PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 07 February 2001 (07.02.01)	
International application No. PCT/GB00/02471	**Applicant's or agent's file reference** 57.0328WOPCT
International filing date (day/month/year) 22 June 2000 (22.06.00)	**Priority date** (day/month/year) 23 June 1999 (23.06.99)
Applicant PAPANASTASIOU, Panos	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   22 December 2000 (22.12.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Pascal Piriou Telephone No.: (41-22) 338.83.38

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 57.0328WOPCT	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/02471	International filing date *(day/month/year)* 22/06/2000	Priority date *(day/month/year)* 23/06/1999
International Patent Classification (IPC) or national classification and IPC E21B49/00		
Applicant SCHLUMBERGER HOLDINGS LIMITED et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand 22/12/2000	Date of completion of this report 29.03.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Str mmen, H Telephone No. +49 89 2399 7345

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

   Description, pages:

   1-2 as originally filed

   Claims, No.:

   1-9 as originally filed

   Drawings, sheets:

   1/3-3/3 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-9
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-9
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-9
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Reference is made to the following documents:

D1: NOBUO MORITA: 'Field and Laboratory Verifications of Sand Production Prediction Models' SPE, vol. 27341, 7 - 10 February 1994, pages 19-28, XP002146574

D2: ZHANG ET AL.: 'Mechanical Strength of Reservoir Materials: Key Information for Sand Prediction' SPE, no. 49134, 27 - 30 September 1998, pages 423-430, XP000937927

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

V-1 D1, which is considered the closest prior art, discloses the subject-matter of claim 1 as follows:

A method of predicting the failure of a rock formation surrounding a subterranean cavity (p. 19, last section l. 3-5 and last 4 lines), comprising the steps of
-measuring a set of parameters relating to pressure conditions and stresses in the rock formation surrounding the subterranean cavity (p. 24, last section, lines 1-3 and part (c) and (d));
-using the set of parameters to determine a rock strength (p. 24, last section, lines 1-3);
-determining a first characteristic length relating to the size of the cavity (p. 22, left column, see text under (1));
-determining a second characteristic length relating to the grain size of the rock formation surrounding the cavity (p. 22, left column, see text under (1));
-correcting said rock strength (page 24, right column, l. 5-6; and
-using a failure criterion* and the corrected rock strength to predict a condition under which the rock formation is expected to produce debris (page 19, right col., first eight lines of second paragraph).

*) According to the applicant, the use of a failure criterion is already known, see the description on page 2, l. 27-30.

The apparatus according to claim 1, therefore differs with respect to D1 in using the first and second characteristic lengths to determine a correction for the rock strength.

The apparatus according to claim 1 is therefore new and the claim meets the novelty requirements of Article 33(2) PCT.

V-2 The distinguishing features of claim 1 relates to the underlying problem of obtaining an indicator of relevant downhole physical dimensions for error correction.

The fact that the determination of rock strength is prone to error is clear from both D1 (p. 25, Conclusions) and D2 (p. 424, left col. first section, last 8 lines).

In particular, D1 teaches that such errors should be corrected (p. 24, right column, l. 1-6). But even when the skilled man considers what is said on page 22, left column, step (2) "cavity size is not close to grain size", it would not be obvious to him to take these two factors and use them for error correction. Neither of the other cited documents in the International Search Report provide hints in this direction and therefore the method step of claim 1 of using said characteristic lengths as correction involves an inventive step such that claim 1 meets the requirements of Article 33(3) PCT.

V-3 Since claims 2-9 depend upon claim 1, these claims also meet the requirements of Article 33(2) and (3) PCT.

<u>Re Item VII</u>

Certain defects in the international application

VII-1 Independent claim 1 is not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from D1 being placed in the preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in the characterising part (Rule 6.3(b)(ii) PCT).

If, however, the applicant is of the opinion that the two-part form would be inappropriate, then reasons therefor should be provided in the letter of reply. In addition, the applicant should ensure that it is clear from the description which features of the subject-matter of claim 1 are already known in combination from D1 (see the PCT Guidelines, III-2.3a).

VII-2 Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in D1 and D2 are not mentioned in the description, nor are these documents identified therein.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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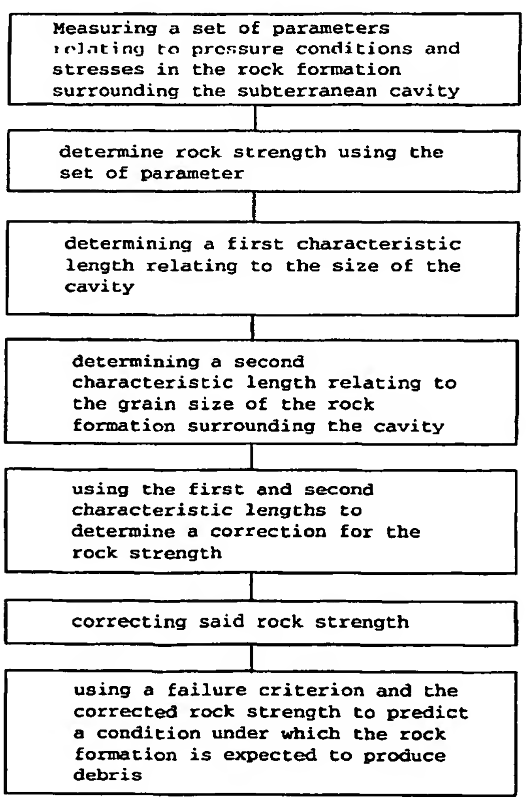
[Continued on next page]

(54) Title: CAVITY STABILITY PREDICTION METHOD FOR WELLBORES



(57) Abstract: A method of predicting the failure of a rock formation surrounding a subterranean cavity, including measuring a set of parameters relating to pressure conditions and stresses in the rock formation surrounding the cavity; using the set of parameters to determine a rock strength; determining a first characteristic length relating to the size of the cavity; determining a second characteristic length relating to the grain size of the rock formation surrounding the cavity; using the first and second characteristic lengths to determine a correction for the rock strength; correcting said rock strength; and using a failure criterion and the corrected rock strength to predict a condition under which the rock formation is expected to produce debris. The results of the prediction can be used to monitor wellbore stability while drilling or optimize the production parameters for a hydrocarbon reservoir.

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Published:

— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Cavity Stability Prediction Method for Wellbores

This invention relates to a method of estimating or predicting the stability of cavities in a subterranean formation. It further pertains to using such estimates to control and set operation parameters for drilling and producing hydrocarbon wells.

BACKGROUND OF THE INVENTION

For the production of hydrocarbon wellbores are drilled into subterranean formations. Subsurface formations encountered in oil and gas drilling are compacted under in situ stresses due to overburden weight, tectonic effects, confinement and pore pressure. When the wellbore is drilled in a formation, the rock near the wellbore is subjected to increased shear stresses due to a reduction in confinement at the wellbore face after removal of the rock from the hole. Compressive failure of the rock near the wellbore will occur if the rock does not have sufficient strength to support the increased shear stresses imposed upon it.

Formation stability problems are not only encountered during the drilling of the wellbore. For the production of hydrocarbons, the hydrocarbon bearing formation is usually perforated or fractured to enable and stimulate the fluid flow into the wellbore. When producing from unconsolidated or weakly-consolidated reservoirs, the formation tends to produce particulates (e.g. sand) along with the hydrocarbons.

Formation sand is produced when the combined effects of fluid drag and near-wellbore stresses cause disaggregation near the perforation or fracture. Individual grains of sand are detached

from the matrix forming the formation. At relatively low flow rates, fluid drag does not affect the stability, but as flow rate increases, drag forces become sufficiently high to remove sand particles from the matrix.

Flowrate from a formation is normally controlled by the perforation drawdown pressure (DP) which is the difference between the pore pressure (p_w) in the formation and the bottomhole pressure (P_0) and can hence be expressed as DP= $P_0 - p_w$.

The critical drawdown pressure (CDP) is the value of DP at which the rock matrix surrounding the perforation begins to de-stabilize. Its value is determined by the maximum calculated rock strength.

To model the maximum rock strength classical elastic and elasto-plastic theories, failure criteria and fracture mechanics have been applied. Models use empirically or semi-empirically derived rock strength values to predict formation behavior by using classical theories and stress, pore pressure and empirically derived strength data from various wells.

There are several methods for predicting when for example sand production will occur in a particular well. Such methods are disclosed and discussed in the US Patent No 5,497,658 and references contained therein. Known rock failure criteria as discussed in this and other published document are referred to as Mohr-Coulomb, critical state, Drucker-Pager model or as extended Von Mises criterion

To apply the failure criteria it is necessary to measure rock properties and the formation fluid properties from core samples, wellbore logs, and the like.

It is therefore an object of the present invention to provide a novel method of estimating the strength of cavities in the subterranean formation, particulary the initiation of sand production in subterranean (sandstone) formations.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided a method of predicting the failure of a rock formation surrounding a subterranean cavity, including the steps of measuring a set of parameters relating to pressure conditions and stresses in the rock formation surrounding the cavity; using the set of parameters to determine a rock strength; determining a first characteristic length relating to the size of the cavity; determining a second characteristic length relating to the grain size of the rock formation surrounding the cavity; using the first and second characteristic lengths to determine a correction for the rock strength; correcting said rock strength; and using a failure criterion and the corrected rock strength to predict a condition under which the rock formation is expected to produce debris.

A cavity can be a wellbore without lining (open hole) or perforation tunnels or other spaces created in a subterranean formation by using chemical or physical forces such as explosives and drilling equipment.

The set of parameters used to characterize the formation surrounding the cavity may include measurement as performed by logging devices, such as sonic, gamma-ray logging devices or NMR based logging devices. Important parameters are for example density or porosity, clay content, or p- and s-wave slowness.

The characteristic length relates to the dimensions of a cavity or grain and is preferably the diameter or radius or the closest approximation of the diameter or radius, given the irregular dimensions of those subterranean objects.

The results of the prediction can be used to monitor wellbore stability while drilling or optimize the production parameters for a hydrocarbon reservoir.

The normalization of the cavity dimension or length with the grain size yields a correction factor that can be used to derive an apparent rock strength. In this way, the scale and plasticity effects are lumped into an apparent strength calculation. This apparent rock strength can be used with estimates of in-situ stresses and pore pressure in a 3-D poroelastic model and failure criterion as Mohr-Coulomb for the calculation of the critical parameters related to the stability of the cavity, such as draw-down pressure and the onset of sand production.

Combined with the appropriate measuring-while-drilling (MWD) or logging-while-drilling (LWD) technology, it can be converted into a prediction tool to estimate the rock stability during drilling operation in real time. As such it could contribute significantly to the prevention of stuck-pipe problems, currently the cause of significant losses in the oilfield industry.

These and other features of the invention, preferred embodiments and variants thereof, possible applications and advantages will become appreciated and understood by those skilled in the art from the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic drawing of a wellbore and a perforation tunnel illustrating the directions of stresses;

FIG. 2 shows the critical draw-down pressure curve for a simulated reservoir; and

FIG. 3 charts steps of the present invention.

MODE(S) FOR CARRYING OUT THE INVENTION

The underlying idea is to use log-data (mainly sonic data) for the derivation of rock elastic constants and formation strength parameters. These parameters can be used with estimates of in-situ stresses and pore pressure in a 3-D poro-elastic model and Mohr-Coulomb failure criterion for the calculation of the critical draw-down pressure.

The method described below assumes clean sandstone as formation material.

The bulk porosity can be derived from the bulk density ρ_b of a fluid saturated porous rock, which is given by

[1] $$\rho_b = \varphi\rho_f + (1 - \varphi)\rho_s ,$$

where ρ_s is the density of the solid grains and ρ_f is the fluid density. Solving for the bulk porosity results in

[2] $$\varphi = \frac{\rho_s - \rho_b}{\rho_s - \rho_f}$$

Approximate default values can be assumed for both densities, e.g., ρ_s = 2.75 g/cm^3 and ρ_f = 1.1 g/cm^3.

The elastic parameters are computed from log compressional and shear wave velocities. Methods and apparatus to perform the required measurements are known as such in the art. For example, the United States Patents 4,862,991, 4,881,208 and 4,951,267 refer to logging tools for measuring shear and compressional wave slowness. The Schlumberger DSI™ tool for conventional logging or the ISONIC™ tool for logging-while-drilling are capable of measuring the required data. Reference to those tools are found for example in the Schlumberger Oilfield Review, Spring 1998, 40-66.

The elastic parameters of the formation as used by the present invention can be determined using the compressional and shear wave velocities log data. The Poisson ratio ν, the shear modulus G, the Young's modulus E and the bulk modulus K are calculated from the p and s wave slownesses (i.e. the reciprocal of the velocity) , Dt_c and Dt_s, according to equations:

[3] $$\nu = \frac{0.5(Dt_s / Dt_c)^2 - 1}{(Dt_s / Dt_c)^2 - 1}$$

[4] $$G = \frac{\rho_b}{Dt_s^2}\alpha$$

[5] $$E = 2G(1 + \nu)$$

[6] $$K = \frac{E}{3(1 - 2\nu)}$$

The rock strength parameters can be calculated in terms of the uniaxial (or unconfined) compresssive strength UCS from the empirical correlations known as Coates and Denoo equation:

[7] $$UCS = (114 + 97V_{sh})\ K(\text{in mio. psi})\ E(\text{in mio. psi})$$

where the clay content V_{sh} can be determined using for example gamma ray logs or information from core.

The pore pressure, P_0, is given by the reservoir pressure. Methods and apparatus to measure the reservoir pressure (and the wellbore pressure p_w)are known and reference is made to the United States Patent 5,789,669 for details of such measurements. The reservoir pressure is likely to vary with time according to the predicted performance of the reservoir.

The vertical in-situ stress σ_v (illustrated by FIG. 1) is estimated from the overburden weight. The magnitude of the minimum horizontal stress can be obtain either from consolidation theory according to

[8] $$\sigma_h = \frac{\nu}{1 - \nu}\sigma_v + \frac{1 - 2\nu}{1 - \nu}\beta P_0$$

where β is the Biot coefficient, or from frictional equilibrium. If possible, a stress measurement or extended leak-off test should be used to verify which assumption gives better estimates.

Finally, in a tectonic environment the horizontal stresses are unequal

[9] $$\sigma_H = K\,\sigma_h$$

The ratio between horizontal stresses can be estimated from borehole breakouts or by the simulation of field tectonic movement using finite elements. In general as much information as possible should be used in constraining the values of the horizontal stresses.

In the following the methodology for calculating the optimum draw-down pressure DP based on 3-D elastic solution. The basic equations are known. The known 3-D elastic solution is augmented with extra terms for taking into account for the gradient of pore or reservoir pressure during production.

As illustrated by FIG.1, the method can be applied to estimate the stability of sections of the wellbore or to estimating the stability of other cavities such as perforation tunnels.

Transforming the parameters from a vertical into a wellbore coordinate system, the stresses at a point on the borehole wall $(r = R)$ and at an angle θ from the axis x are given by

[10] $$\sigma_r = p_w$$

[11] $$\sigma_\theta = (\sigma_{xx} + \sigma_{yy} - p_w) - 2(\sigma_{xx} - \sigma_{yy})\cos 2\theta - - 4\sigma_{xy}\sin 2\theta - (P_0 - p_w)\beta\frac{1-2\nu}{1-\nu}$$

[12] $$\sigma_z = \sigma_{zz} - 2\nu(\sigma_{xx} - \sigma_{yy})\cos 2\theta - - 4\sigma_{xy}\sin 2\theta - (P_0 - p_w)\beta\frac{1-2\nu}{1-\nu}$$

[13] $$\sigma_{\theta z} = - 2\sigma_{xz}\sin\theta - 2\sigma_{yz}\cos\theta$$

[14] $\sigma_{rz} = 0$

where the original input in-situ stresses, σ_H, σ_h, σ_v have first been transformed into the Cartesian components of a wellbore coordinate system and then, using eqs [10]-[14], into cylindrical wellbore coordinates. The parameter p_w denotes the pressure in the wellbore. For a weak reservoir sandstone a reasonable value for the Biot coefficient is $\beta = 1$.

The principal stresses can be found from the eigenvalues of the stress tensor

[15] $$[\sigma] = \begin{bmatrix} \sigma_r & \sigma_{r\theta} & \sigma_{rz} \\ \sigma_{\theta r} & \sigma_\theta & \sigma_{\theta z} \\ \sigma_{zr} & \sigma_{z\theta} & \sigma_z \end{bmatrix}$$

using the Matlab™ function princ = eigs(s), and can be put in order, σ_3, σ_2 and σ_1, the maximum compressive stress.

The Mohr-Coloumb failure criterion can be expressed in the following form

[16] $f = UCS - \sigma'_1$

The effective stress σ'_1 at the borehole wall is given by

[17] $\sigma'_1 = \sigma_1 - \beta p_w$.

It was found that the failure criterion, eq. [16], and any other failure criterion using the uniaxial compressive strength UCS can be improved by taking into account the scaling effect, i.e. the characteristic dimension of the perforations through which

hydrocarbons are produced. Experimental data showed that by introducing a scaling factor including the grain size of the formation, the estimates of the critical production parameters can be improved and applied to a broader range of rock types.

Applying the scaling factor to the uniaxial compressive strength UCS yields the correction

$$[18] \qquad UCS_{appar.} = 2\ UCS\ a \left(\frac{D_{perf}}{D_{grain}} \right)^{-n}$$

where UCS is defined by eq. [7] and D_{perf} is the diameter of the perforation and D_{grain} is the diameter of the grains of the rock formation. The fitting parameters a and n are determined as 16.1064 and 0.3374, respectively, by may vary to some extend depending on the fitted data and fitting algorithm.

In the absence of a measured grain size, D_{grain} can be estimated using prior knowledge of the rock or, at worst, simply approximated by a constant default value. Experimental data suggest 0.2 mm for such a default value.

The corrected $UCS_{appar.}$ can be used in the failure criterion [16] and standard mathematical optimization procedures to produce a better estimate of the maximal rock strength and, hence, a better estimate of the maximum draw-down pressure.

FIG 2 illustrates a simulated example using input values taken from known parameters of a drilled well in the North Sea.

The input parameters are

Insitu stresses:

Vertical stress σ_v = 24.82 MPa;

Min. horizontal stress σ_h = 15.63 MPa;

Max. horizontal stress σ_h = 17.19 MPa;

Formation pressure P_0 = 11.03 MPa.

Rock Parameters:

Poisson ratio ν = 0.25;

Uniaxial compressive strength UCS = 4.07 MPa;

Grain size D_{grain} = 0.2 mm

Well data:

Well diameter D_{well} = 0.20 m

Inclination I = 90 degrees

Azimuth a= 0 degrees

Perforation data

Perforation diameter D_{perf} = 0.01 m

Phasing ϕ = 55 degrees

The horizontal stresses are assumed to be equal and they are calculated from the consolidation eq. [9]. The formation strength is calculated in terms of the corrected $UCS_{appar.}$ from available log data and the correlation function [7].

FIG. 2 shows the optimum wellbore pressure for sand-free production calculated using the above approach at the beginning of (0% depletion) and during production. During depletion it is assumed that the total vertical in-situ stress remains unchanged, therefore, the vertical effective stress increases by the same amount the pore pressure decreases. The variation of the effective horizontal stresses is taken empirically to be 50%

of the variation in the vertical effective stress. Though safe production is possible within the area limited by calculated curve for the onset of sand production (marked by circles), maximum hydrocarbon is achieved by setting the well parameters, i.e. most notably the wellbore pressure as close to the curve as possible.

Using the same input data and stability model (i.e. UCS) without the correction proposed by the present invention, the optimization predicts that the wellbore can not be produced without sand.

CLAIMS

1. A method of predicting the failure of a rock formation surrounding a subterranean cavity, comprising the steps of

- measuring a set of parameters relating to pressure conditions and stresses in the rock formation surrounding the subterranean cavity;

- using the set of parameters to determine a rock strength;

- determining a first characteristic length relating to the size of the cavity;

- determining a second characteristic length relating to the grain size of the rock formation surrounding the cavity;

- using the first and second characteristic lengths to determine a correction for the rock strength;

- correcting said rock strength; and

- using a failure criterion and the corrected rock strength to predict a condition under which the rock formation is expected to produce debris.

2. The method according to claim 1 wherein the set parameters includes sonic wave slowness.

3. The method according to claim 1 wherein the set parameters includes the formation density.

4. The method according to claim 1 wherein the set parameters includes the wellbore and formation pressure.

5. The method according to claim 1 wherein the failure criterion is a shear failure criterion (Mohr-Coulomb).

6. The method according to claim 1 wherein the failure criterion includes a term corresponding to an uniaxial compressive strength (UCS).

7 The method according to claim 1 wherein the correction includes forming the quotient of the first and the second characteristic length.

8. The method according to claim 1 further including the step of determining a wellbore production pressure using the failure criterion.

9. The method of claim 1 wherein the set of parameters relating to pressure conditions and stresses in the rock formation surrounding the cavity are at least partly measured while drilling.

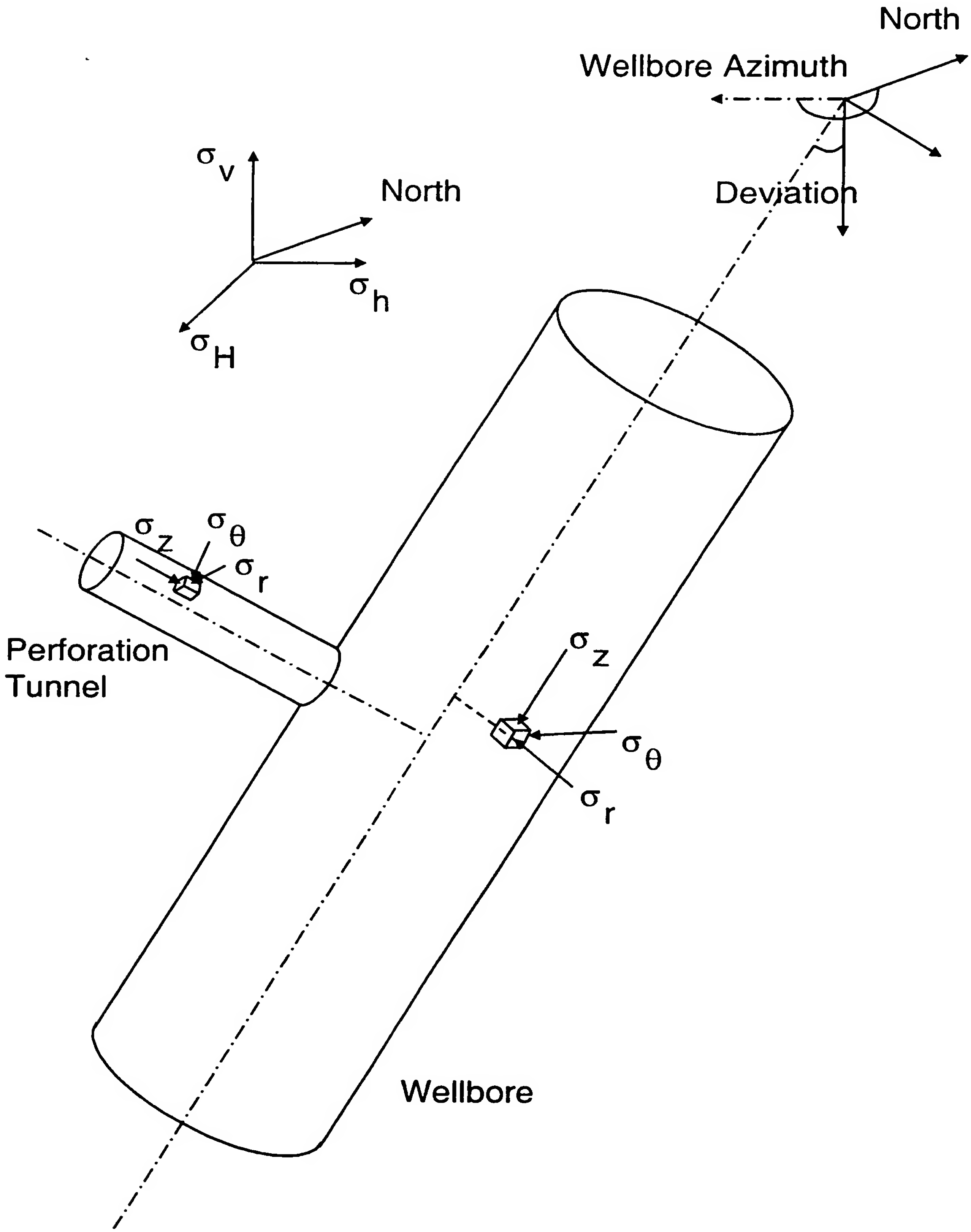
North
Wellbore Azimuth
Deviation
σ_v
North
σ_h
σ_H
σ_z
σ_θ
σ_r
Perforation Tunnel
σ_z
σ_θ
σ_r
Wellbore

FIG. 1

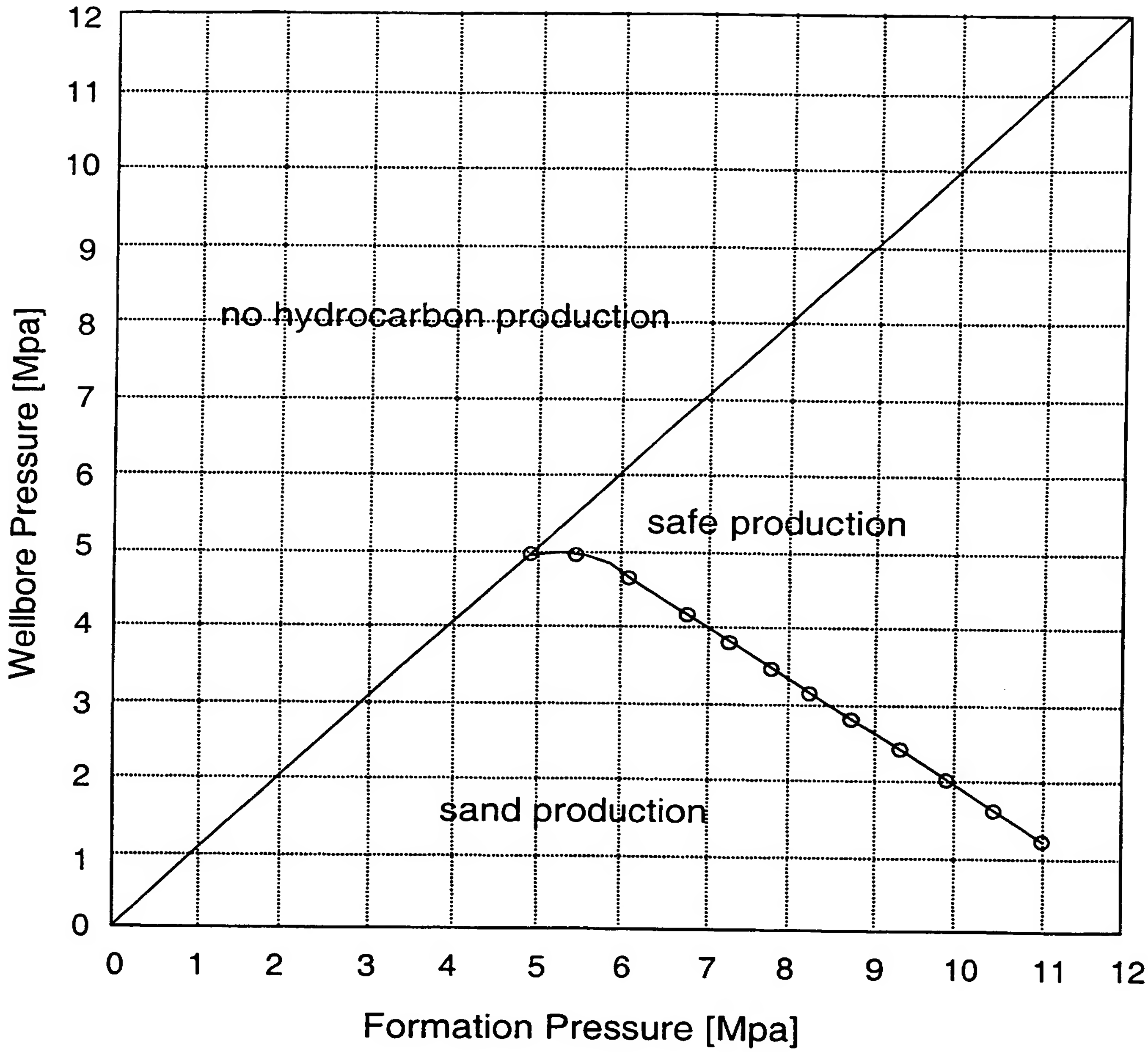
Wellbore Pressure [Mpa]
12
11
10
9
8
7
6
5
4
3
2
1
0
no hydrocarbon production
safe production
sand production
0 1 2 3 4 5 6 7 8 9 10 11 12
Formation Pressure [Mpa]

FIG. 2

Measuring a set of parameters relating to pressure conditions and stresses in the rock formation surrounding the subterranean cavity

determine rock strength using the set of parameter

determining a first characteristic length relating to the size of the cavity

determining a second characteristic length relating to the grain size of the rock formation surrounding the cavity

using the first and second characteristic lengths to determine a correction for the rock strength

correcting said rock strength

using a failure criterion and the corrected rock strength to predict a condition under which the rock formation is expected to produce debris

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02471

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B49/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, TULSA

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 907 034 A (SUMAN JR GEORGE O) 23 September 1975 (1975-09-23) column 5, line 61 - line 66 ---	1-9
A	NOBUO MORITA: "Field and Laboratory Verifications of Sand Production Prediction Models" SPE, vol. 27341, 7 - 10 February 1994, pages 19-28, XP002146574 page 19 page 24, column 2 -page 25, column 2 ---	1-9

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2000	26/09/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Garrido Garcia, M

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02471

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ZHANG ET AL.: "Mechanical Strength of Reservoir Materials: Key Information for Sand Prediction" SPE, no. 49134, 27 - 30 September 1998, pages 423-430, XP000937927 abstract	1-9

2

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/02471

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3907034 A	23-09-1975	US 3918522 A	11-11-1975
		CA 1020084 A	01-11-1977
		GB 1510886 A	17-05-1978
		MY 34481 A	31-12-1981
		CA 1023258 A	27-12-1977
		GB 1501504 A	15-02-1978
		MY 33481 A	31-12-1981

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:
WANG, William, L.
Schlumberger Cambridge Research
Limited
High Cross
Madingley Road
Cambridge CB3 0EL
ROYAUME-UNI

Date of mailing (day/month/year)
04 January 2001 (04.01.01)

Applicant's or agent's file reference
57.0328WOPCT

IMPORTANT NOTICE

International application No.	**International filing date** (day/month/year)	**Priority date** (day/month/year)
PCT/GB00/02471	22 June 2000 (22.06.00)	23 June 1999 (23.06.99)

Applicant
SCHLUMBERGER HOLDINGS LIMITED et al

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   AU,KP,KR,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   AE,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,CA,CH,CN,CR,CU,CZ,DE,DK,DM,EA,EE,EP,ES,FI,GB,GD, GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MN,MW,MX, NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,ZA,ZW
   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on
   04 January 2001 (04.01.01) under No. WO 01/00962

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a **demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No. (41-22) 740.14.35	Authorized officer J. Zahra Telephone No. (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 57.0328WOPCT	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/ 02471	International filing date *(day/month/year)* 22/06/2000	(Earliest) Priority Date *(day/month/year)* 23/06/1999
Applicant SCHLUMBERGER HOLDINGS LIMITED et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [X] as suggested by the applicant.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02471

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B. FIELDS SEARCHED
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, TULSA

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Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Authorized officer Garrido Garcia, M

2

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